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Rotorcraft Acceleration and Climb Performance Model

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Final Report

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16. Abstract

This report documents the methodology used in developing the helicopter departure profiles presented in "Helicopter Physical and Performance Data" DOT/FAA/RD-90/3. Each step involved in creating the profiles is examined. In particular, the Helicopter Departure Profile (HEDPRO) program is described in detail. This program converts helicopter performance data and departure procedures into departure profile data.

The first step in developing profiles was to identify the departure procedures recommended by the manufacturers. Additionally, a safe confined area departure procedure needed to be developed. Next, climb and acceleration performance data specific to each helicopter and atmospheric condition was generated. This required extensive data to be collected for each helicopter. This data was then used in the Helicopter Sizing and Performance Computer Progam (HESCOMP) developed by NASA/Boeing to compute helicopter performance data.

The last two steps were to compute and graph the profiles. HEDPRO was developed specifically for this project to compute the departure paths by determining the height/distance points of the path from the helipad. These points were then graphed to develop the final product.

This methodology is described in sufficient detail so as to be a valuable aid should other helicopter departure profiles need to be determined.

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Helicopter Performance
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1.0 INTRODUCTION

This report documents the methodology used to determine helicopter departure profiles as presented in Helicopter Physical and Performance Data, DOT/FAA/RD-90/3. Its objective is to sequentially describe each of the steps involved in creating these profiles and specifically to provide a detailed description of the Helicopter Departure Profile (HEDPRO) program which converts helicopter climb/acceleration data and departure procedures into departure profile data. The five steps required to produce climb profiles are:

1. determine the departure procedures to be used and obtain the necessary data,
2. compile data needed to compute helicopter climb performances,
3. generate the climb performance data through the use of the Helicopter Sizing and Performance Computer Program (HESCOMP),
4. incorporate the climb performance data and departure procedures into HEDPRO to generate helicopter departure profile data, and
5. generate the departure profile.

2.0 DEPARTURE PROCEDURES

Two sets of departure procedures are used for the models; one being those recommended by the manufacturers, and the other, known as the Height-Velocity Diagram + 5 Knots Procedure (HV+5 Knots), which was created to aid this study.

The manufacturers' recommended procedures for the eight helicopters studied, table 1, varied considerably in both the operational application and the amount of detail provided. Two of the eight manuals provided specific short-field or confined area procedures while one manual did not recommend either departure speeds or altitudes. Most of the flight manuals did not have any procedures for short field takeoffs, and as a result profiling the departure paths from their recommended procedures improperly degraded the aircraft's climbout capability in confined areas.

In order to develop uniform departure data that specifically addressed the confined heliport issue, a uniform short field departure procedure was designed for each of the helicopters in the study. This procedure is termed the Height-Velocity Diagram + 5 Knots Procedure (HV+5 Knots) and is based on adding 5 knots to the minimum airspeed identified by the "knee" of the upper avoid area in the height velocity diagram (shown in figure 1). A description of the flight procedure is:

> Establish a hover in ground effect at the altitude recommended by the manufacturer, apply forward cyclic and raise the collective to establish a level acceleration to effective translational lift, apply aft cyclic to achieve an accelerating climb to a speed of 5 knots above the highest value shown in the upper avoid area of the applicable H-V diagram and an altitude that remains clear of the upper avoid area. Continue climb at that speed.

The use of the H-V diagram in defining procedures for the confined heliport pointed out several differences in how manufacturers present the avoid area in the flight manuals. In general, three types of H-V diagrams are contained in the eight flight manuals used in the study. They are the maximum conditions diagram, the density altitude diagram, and the operational conditions diagram. Examples of these H-V diagrams are shown in appendix A.

Four of the modeled helicopters use the maximum conditions diagram which consists of two graphs. The first graph is an H-V diagram for conditions of maximum helicopter gross weight and sea level standard temperature conditions. The second chart establishes gross weight limitations as the density altitude increases. With the maximum conditions diagram, the avoid area remains constant regardless of operating conditions, therefore departure airspeeds and altitudes will not change under varying pressure altitudes, temperatures or helicopter weights.

Two of the modeled helicopters use the density altitude diagram which consists of several interrelated graphs representing different gross weights. The density altitude H-V diagram permits the avoid areas to decrease as aircraft gross weight decreases, therefore the helicopter can begin its climb at a slower airspeed.

TABLF 1 MANUFACTURER'S RECOMMENDED DEPARTURE PROCEDURES

Helicopter	Flight Manual Procedure
F28F	Maximum performance takeoff in a confined area. Stabilize at hover of 2 ft. aligned with desired takeoff course. Check hover power, smoothly apply forward cyclic to accelerate to effective translational lift. Apply aft cyclic to maintain best angle of climb speed (35 mi/hr) to clear barriers. If distance to barriers precludes level acceleration to translational lift, use a coordinated climb and acceleration.
MD 500E	Follow recommended takeoff profile shown on H-V diagram. (Level acceleration to 35 knots, climbing acceleration to 60 knots at a height of 70 ft, climb at 60 knots to desired altitude)
B 206B3	Establish hover, turn to desired heading, accelerate to obtain desired rate of climb and airspeed.
AS 355F	Establish hover in ground effect, synchronize engines, initiate forward flight in a slight climb to an indicated airspeed of 55 knots, V_Y.
BO 105CBS	Establish hover in ground effect at about 6 ft, level acceleration to 40 knots, accelerating climb to 45 knots at 30 ft, climbout at 45 knots, V_Y.
S76A	Category A Establish a hover in ground effect at about 5 ft, accelerate foreward and maintain a 5 to 10 ft. wheel height, at 35 knots rotate nose up and maintain 35 knots, at CDP of 40 ft accelerate to V_Y. Category B Establish a hover in ground effect at 5 ft, accelerate forward and maintain a 5 to 10 ft. wheel height, at 45 to 50 knots raise nose to maintain 52 knots, climb until obstacles are cleared.
AS 332	Category A short field procedure Determine takeoff weight, CDP, V_{TOSS} and V_Y; establish hover in ground effect at 15 ft; increase pitch to achieve a climbing acceleration to V_{TOSS} at 35 ft; accelerating climb to V_Y at 200 ft. retract gear at V_Y.

TABLE 1 MANUFACTURER'S RECOMMENDED DEPARTURE PROCEDURES (Continued)

	Category B short takeoff procedure Hover at 15 ft, accelerate at constant height until there is a positive airspeed indication, accelerating climb to 40 knots at 100 ft, climb to cruise altitude and cruise airspeed.
	Category B vertical procedure (applicable only at conditions where there are no areas to avoid in the H-V diagram) Hover at 15 ft, increase collective pitch until desired altitude is reached, initiate forward flight in the same manner as with the short takeoff procedure.
BV 234LR	Category A Hover at 15 ft, level acceleration to achieve 14^{o} nosedown prior to 30 knots, climb at V_{CDP} to CDP height, accelerate to V_{TOSS}, accelerating climb to V_{Y}.

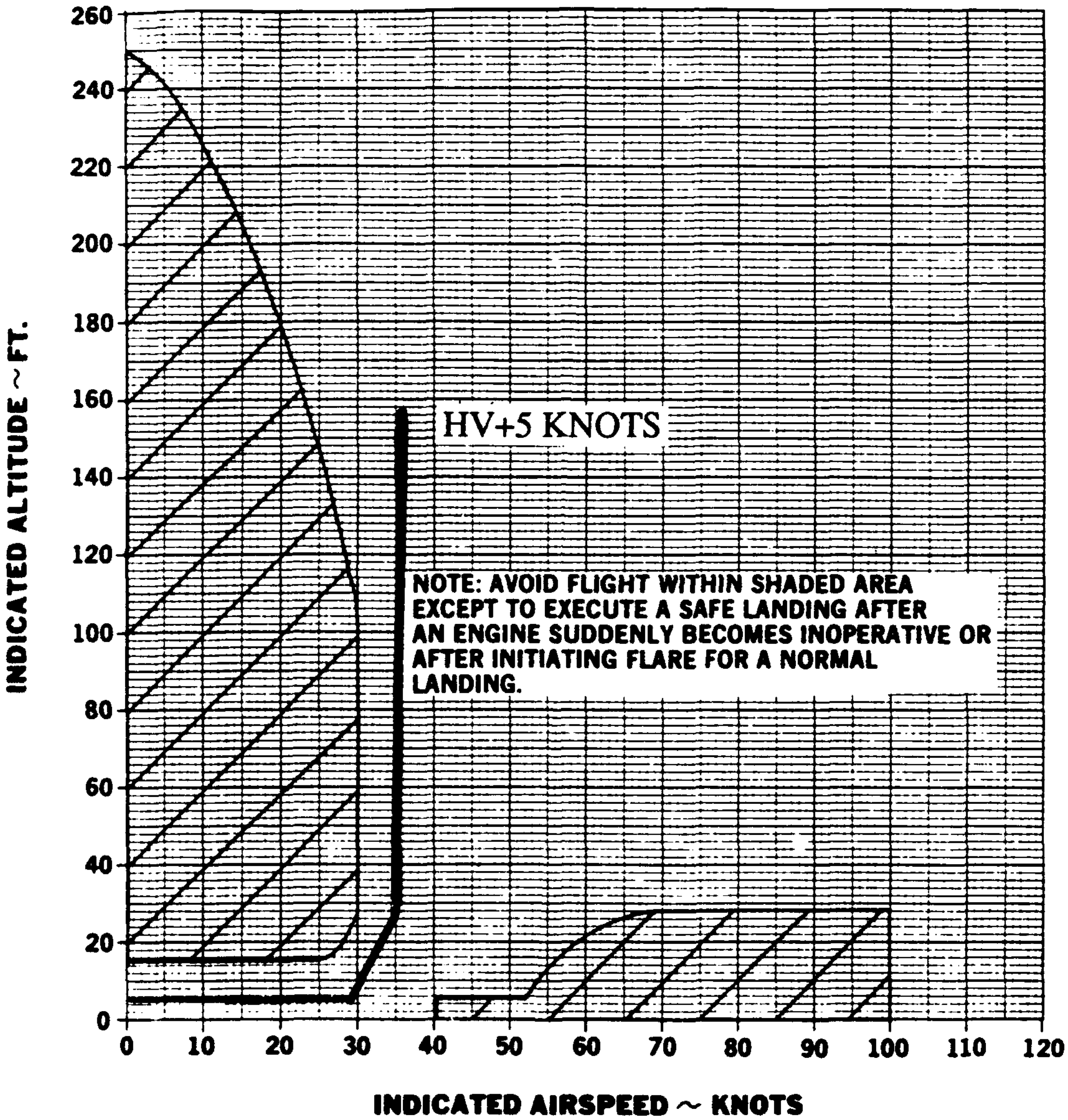

FIGURE 1 HV+5 KNOTS DEPARTURE PROCEDURE

The remaining two modeled helicopters use the operational conditions H-V diagram which consists of a number of interconnecting graphs. The graphs permit the determination of the avoid areas over a broad range of weight and density altitude conditions. As is true with the density altitude H-V diagram, the avoid area changes shape and for twin engine helicopters under conditions of low gross weight/low density altitude the upper avoid area disappears. In such a case the helicopter can depart vertically without flying through the upper avoid area of the H-V diagram.

Both the manufacturer's recommended procedures and the HV+5 Knots procedure can be described by the departure profile and the terms shown in figure 2. This diagram also is used to standardize the terms for later input into the HEDPRO program.

The S76A departure procedures will serve as an example of how to translate departure procedures into usable data for the HEDPRO program. Category A and B procedures were stated in table 1 and from these procedures the following data was derived.

Category A

SKIDHEIGHT = 5 Feet
ROTATESPEEDINDICATED = 35 Knots
HVMAXHEIGHT = 40 Feet
VHVP5INDICATED = V_Y = 52 Knots (calculated from flight manual)

Category B

SKIDHEIGHT = 5 Feet
ROTATESPEEDINDICATED = 45 Knots
HVMAXHEIGHT = 28 Feet
VHVP5INDICATED = 52 Knots

The HV+5 Knots procedure was described previously and along with figure 1 the necessary data was obtained.

SKIDHEIGHT = 5 Feet
ROTATESPEEDINDICATED = 29 Knots
HVMAXHEIGHT = 23 Feet
VHVP5INDICATED = 35 Knots

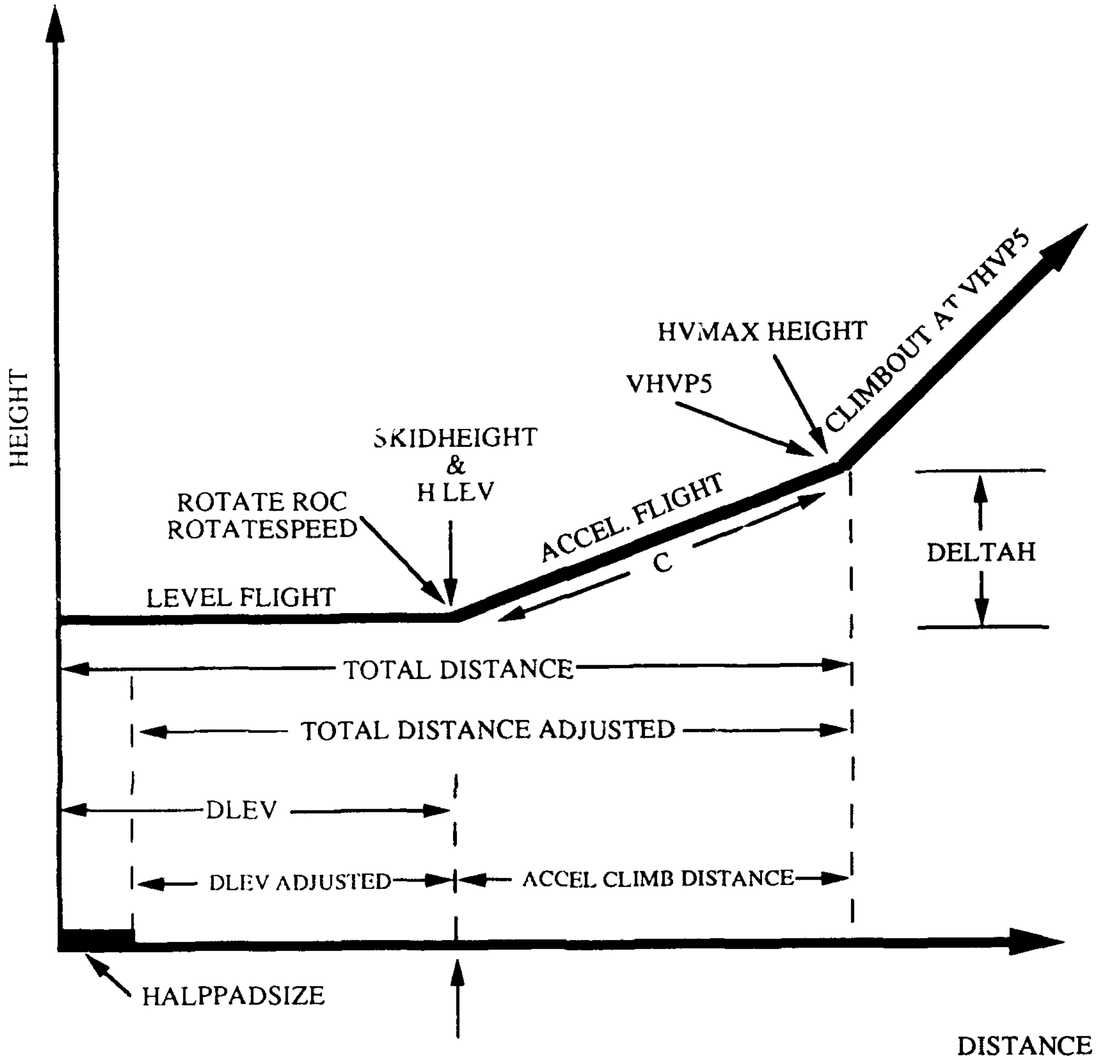

FIGURE 2 HV+5 KNOTS DEPARTURE PROFILE

3.0 HELICOPTER DATA

Helicopter data needed to be compiled both for use in the HESCOMP and HEDPRO programs. The aircraft data needed for the HESCOMP program is extensive but the majority of it was available in the flight manuals. In general, the only data which was not available from the flight manual was the helicopter takeoff power available. In all but one case, the manufacturer provided this data. For the one exception, a close approximation of the power available was computed from performance data in the flight manual.

Aircraft data on each of the models and a description of the parameters were presented in table 1, the physical database file of Helicopter Physical and Performance Data. Individual aircraft data was reviewed by the manufacturer for accuracy and changes were made when necessary. This data was then sent to the University of Maryland, Aerospace Department for use in the HESCOMP calculations.

4.0 GROSS WEIGHT AND DENSITY ALTITUDE

The helicopter departure profiles were developed to present performances for a variety of aircraft weights and departure conditions. A total of 18 profiles were developed for each of the departures based on 3 helicopter gross weights, 3 field elevations and 2 temperature conditions. The three helicopter weights used were the maximum allowable takeoff gross weight, and 85 percent and 70 percent of the maximum gross weight. Field elevations used were at sea level, 2000 feet pressure altitude and 4000 feet pressure altitude. Temperature conditions used were the international standard atmosphere (ISA) temperatures corresponding to the field elevation and ISA temperatures plus 20 degrees Celsius for the additional cases. These temperatures equate to 15 and 35 degrees Celsius at sea level, 11 and 31 degrees Celsius at 2000 feet pressure altitude, and 7 and 27 degrees Celsius at 4000 feet pressure altitude. In all a wide range of realistic takeoff weights and conditions are presented.

5.0 HESCOMP

The Helicopter Sizing and Performance Computer Program (HESCOMP) generates helicopter acceleration and climb performances as a function of airspeed. The program's computations are based on subtracting the power required from the takeoff power available to calculate the excess horsepower at 5 knot airspeed increments. This excess horsepower is then used to compute the acceleration and climb performance data. This data represents the helicopter's maximum capability to either accelerate or climb; but not to do both simultaneously. HESCOMP data for the S76A under conditions of maximum gross weight and standard sea level conditions is presented in table 2.

TABLE 2
S76A CLIMB AND ACCELERATION DATA

TRUE AIRSPEED	RATE OF CLIMB	ANGLE OF CLIMB	ACCELERATION DISTANCE	ELAPSED TIME
0	0	0.00	0.0	0.00
5	0	0.00	8.1	3.04
10	0	0.00	24.3	4.32
15	77	2.90	49.0	5.50
20	295	8.29	79.7	6.54
25	529	11.79	116.5	7.51
30	750	13.85	158.7	8.42
35	940	14.85	207.0	9.30
40	1094	15.11	260.9	10.15
45	1215	14.92	320.5	10.98
50	1307	14.46	387.0	11.81
55	1373	13.84	462.4	12.66
60	1422	13.16	546.9	13.53
65	1455	12.46	644.1	14.45
70	1478	11.77	753.6	15.41
75	1491	11.10	878.5	16.43
80	1494	10.44	1018.6	17.50
85	1483	9.77	1177.5	18.64
90	1464	9.12	1354.9	19.84
95	1437	8.49	1556.4	21.13
100	1401	7.87	1782.1	22.50

HESCOMP was developed by the Boeing Helicopter Company to determine design parameters needed for a helicopter to meet mission requirements. This program is widely accepted by the rotary-wing and V/STOL industry and has been empirically proven to be accurate to within 5 to 10 percent of actual flight performance.

HESCOMP has also been modified by Boeing to include a more accurate representation of low speed flight, more detailed weight algorithms, center of gravity locations, advanced rotor characteristics and maneuver analysis. To adapt HESCOMP to compute acceleration and climb performance capabilities, calculations of seven helicopter characteristics were first computed. These characteristics are: 1) geometric characteristics, 2) engine modeling, 3) airframe download, 4) drag prediction, 5) aerodynamics, 6) rotor performance, and 7) general performance.

Correct specifications of helicopter geometry are essential for HESCOMP's data to be accurate. Physical characteristics collected were total fuselage length, main rotor/fuselage separation distance, tail boom relative position on fuselage, center of gravity locations, lighting and gear configurations, horizontal and vertical tail relative positions, engine nacelle locations and rotor pylon geometry. Fuselage fineness ratios, locations of maximum height and width, and wetted areas were also input. For the tandem rotor helicopter, additional data included rotor overlap, aft rotor pylon geometry and shaft inclination.

Properly computing engine performance is also essential for evaluating performance characteristics. Engine certified specifications were used for each atmospheric condition with flight manual data being the primary source. Parameters which reduce engine power available include increased engine inlet and exhaust temperature and accessory horsepower extraction. Of interest, is that some engines showed large variations in power available with respect to altitude changes while other engines did not. This is due to the Reynold's number effects based on compressor inlet conditions, compressor blade speed, and blade tip speed.

Airframe download is the effect of rotor downwash on the airframe. Airframe shape, perimeter area, and vertical location under the rotor were calculated as a function of fuselage station. Airframe download was then calculated using a semi-empirical method.

Total profile drag was estimated using a detailed skin friction and pressure drag calculation based on empirical trends. Drag estimates for each airframe component were calculated and then summed to provide total minimum drag.

Aerodynamics of the fuselage and stabilizer surfaces were determined at trimmed flight conditions. These aerodynamic effects impact the power required at higher airspeeds.

Main and tail rotor performances are also important in predicting helicopter performance. Main rotor performance was calculated using a combination of momentum theory and empirical corrections. Main and tail rotor performance was correlated with manufacturer supplied data for the hover and minimum power required points.

In addition to the helicopter data, several flight procedural assumptions were made. These assumptions are also important in developing accurate data.

Acceleration distances were computed at a constant altitude in ground effect for all airspeeds. Results showed lower power requirements occurred in ground effect at low airspeeds only. Once the aircraft accelerated beyond about 30 KIAS there was no difference in power required.

Rates of climb and angle of climb were computed at constant airspeeds. Rates of climb were also assumed to be zero unless power available exceeded power required by 5 percent.

The maximum tip path plane used in the calculations varied by helicopter. The S76A, BV234LR and AS355F used a maximum tip path plane of 45 degrees. The other aircraft performance data was computed at a maximum tip path plane of 25 degrees. The difference was due to individual subcontractor's opinions. These conflicting assumptions did affect elapsed times performance data at slower airspeeds. Elapsed times at slower airspeeds, however, were not used in the HEDPRO program and therefore the profiles were not affected. As airspeeds increased, both subcontractors decreased the tip path plane angles and the data became consistent.

Takeoff power (5 minute rating) was used in the calculation when the information was available in the flight manual. If the data was not available, maximum continuous power was used.

Acceleration and climb performance data produced by HESCOMP was then correlated with manufacturer supplied data for all aircraft and confirmed to be accurate. Most flight manuals contained, at a minimum, power required in a hover, best rate of climb speed, and maximum rate of climb.

HESCOMP can be purchased from the National Technical Information Service (NTIS) Springfield, VA. The NTIS control number is 732430120S.

6.0 DEPARTURE PROFILE DATA (HEDPRO PROGRAM)

The Helicopter Departure Profile Program (HEDPRO) uses the HESCOMP data plus supplemental helicopter data (listed in table 3) to produce departure profile data.

TABLE 3
SUPPLEMENTAL DATA REQUIRED BY HEDPRO

Data Required	Input at Program Step Number
HV+5 Knot Procedure	
IAS to CAS Correction	120
Rotor Diameter	130
Max. Gross Wt.	150
VTOSS (IAS)	1080
Skid Ht.	1200
VTOSS Ht.	1340
Rotate Speed Ind.	1140

HEDPRO calculations are based on dividing the departure path into three phases of flight (shown in figure 2). HEDPRO then computes the altitude and distance endpoints of each phase and the time required for the helicopter to fly that phase.

The first and last phases called the level acceleration and climbout phases respectively were straightforward computations. In the level acceleration phase, the helicopter does not climb so the excess horsepower only increases airspeed. Similarly, in the climbout phase, airspeed is constant so the excess horsepower only affects the rate of climb. Since HESCOMP data uses the excess horsepower to generate either maximum aircraft acceleration or maximum rate of climb, the HESCOMP data need only be interpolated to gain accurate results. Other computations that need to be done for these two phases are to convert indicated airspeed which is used in the departure procedures into true airspeed which is used by HESCOMP.

The middle phase of flight called the climbing acceleration phase was the most difficult to accurately compute. The aircraft simultaneously climbs and accelerates during this phase and therefore the excess horsepower is used to do both. HEDPRO computes the time and distance of this phase by calculating independently in small incremental steps the time and distance required for the helicopter to climb and accelerate and then totals the two times. While this methodology is not operationally correct, it yields a close approximation to the actual climbout profile. Additionally, the acceleration phase is short (usually 1 or 2 seconds) and the modeling procedure closely represents the helicopters' takeoff performance.

The departure profile data was then printed (data shown in table 4) and stored in the number two output file. The data contained in the output file provides all the necessary information to create the departure profiles.

TABLE 4 DEPARTURE PROFILE DATA

S76A - Optimum Climb Procedure
12-26-1989 11:11:11
S76A01

Weight = 10,500 Field Elevation = 0 Temp. Dev. = 0
Density Altitude = 0

DLEVEL =	58.07	HLEVEL =	5	TLEVEL =	4.25
DCLOUT =	151.31	HCLOUT =	23	TCLOUT =	5.82
SLOPE = 7.125 DEGREES					
DSLOPE =	109.31	HSLOPE =	15	TSLOPE =	5.14
SLOPE = 8.130 DEGREES					
DSLOPE =	135.53	HSLOPE =	20	TSLOPE =	5.57
SLOPE = 9.462 DEGREES					
DSLOPE =	170.05	HSLOPE =	31	TSLOPE =	6.17
SLOPE = 11.310 DEGREES					
DSLOPE =	165.50	HSLOPE =	33	TSLOPE =	6.25

S76A - Optimum Climb Procedure
12-26-1989 11.11.11
S76A02

Weight = 10,400 Field Elevation = 0 Temp. Dev. = 20
Density Altitude = 2,275

DLEVEL =	134.69	HLEVEL =	5	TLEVEL =	7.03
DCLOUT =	315.17	HCLOUT =	23	TCLOUT =	9.86
SLOPE = 7.125 DEGREES					
DSLOPE =	915.30	HSLOPE =	120	TSLOPE =	17.76
SLOPE = 8.130 DEGREES					
DSLOPE =	1352.76	HSLOPE =	190	TSLOPE =	23.47
SLOPE = 9.462 DEGREES					
DSLOPE =	1682.47	HSLOPE =	283	TSLOPE =	31.06
SLOPE = 11.310 DEGREES					
NO SOLUTION - SLOPE UNACHIEVABLE WITHIN ALLOWABLE RANGE					

HEDPRO was developed by Systems Control Technology, Inc. for this contract and uses GWBasic as its programming language. The HEDPRO program for the S76A using the HV+5 Knots procedure is presented in appendix B. A flow chart and flow narrative of the program are presented in figure 3 and table 5 respectively. Definitions of the terms used in the program are defined in table 6.

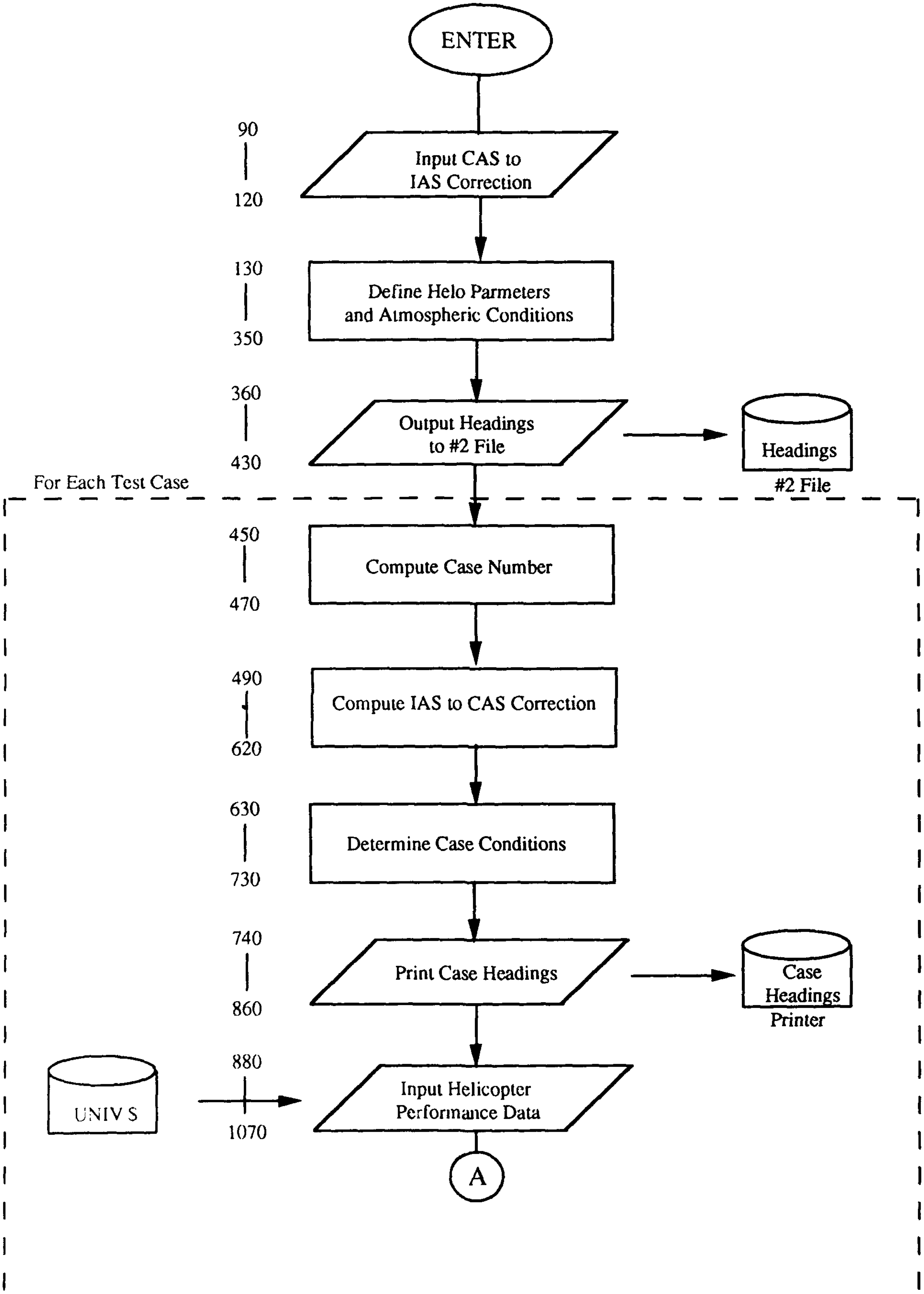

FIGURE 3 FLOW CHART FOR THE HV + 5 KNOTS PROCEDURE

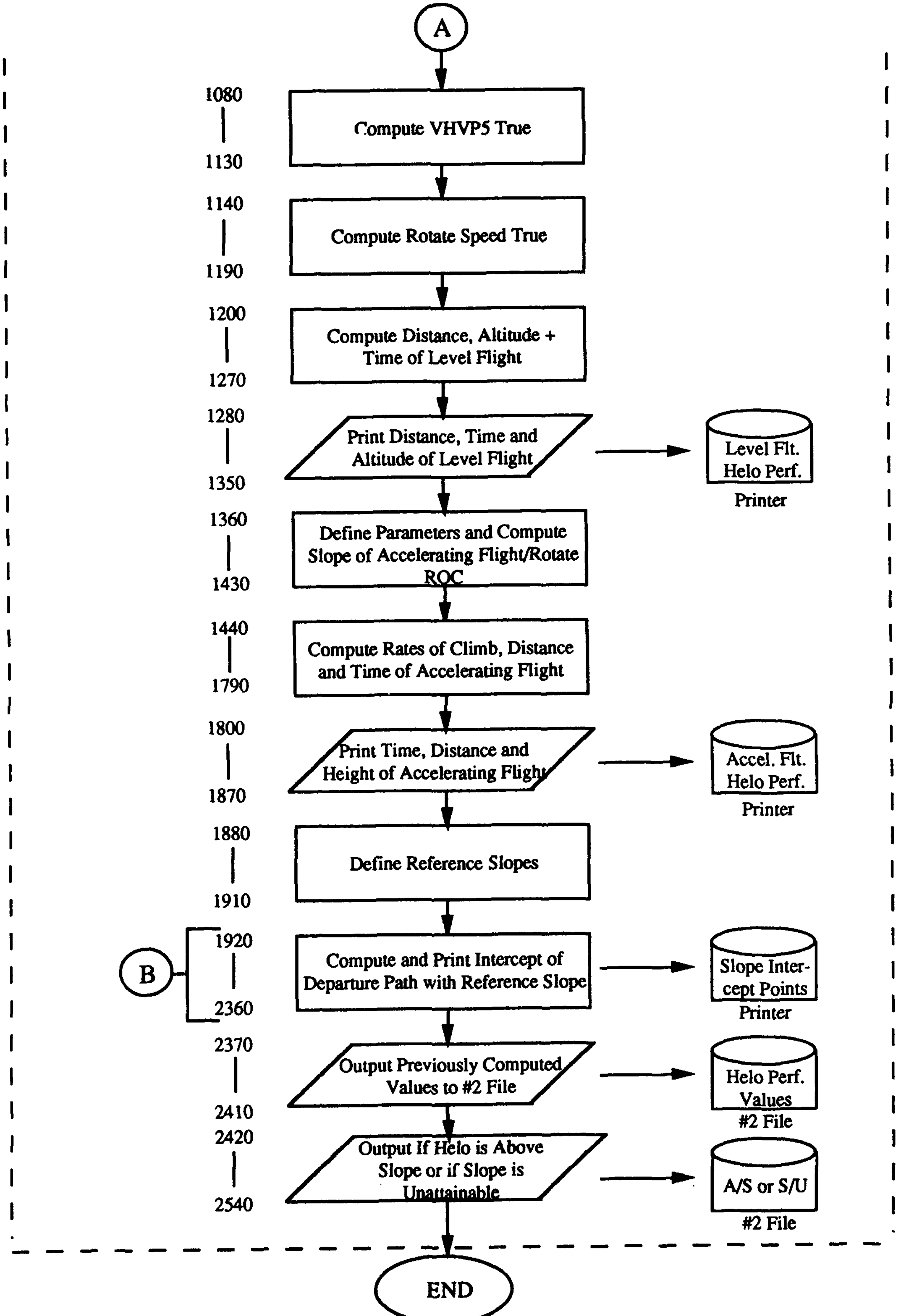

FIGURE 3 FLOW CHART FOR THE HV + 5 KNOTS PROCEDURE (CONTINUED)

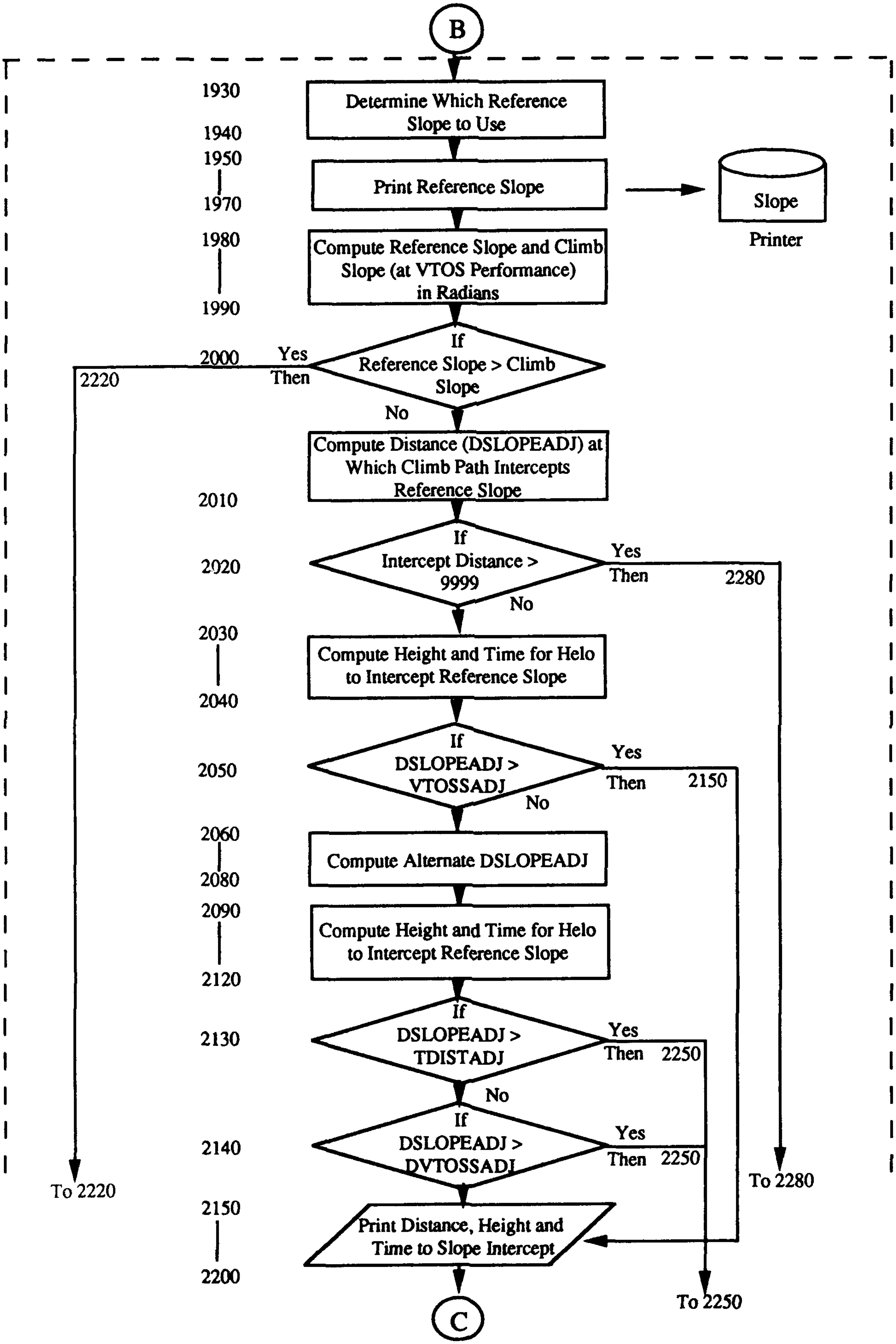

FIGURE 3 FLOW CHART FOR THE HV + 5 KNOTS PROCEDURE (CONTINUED)

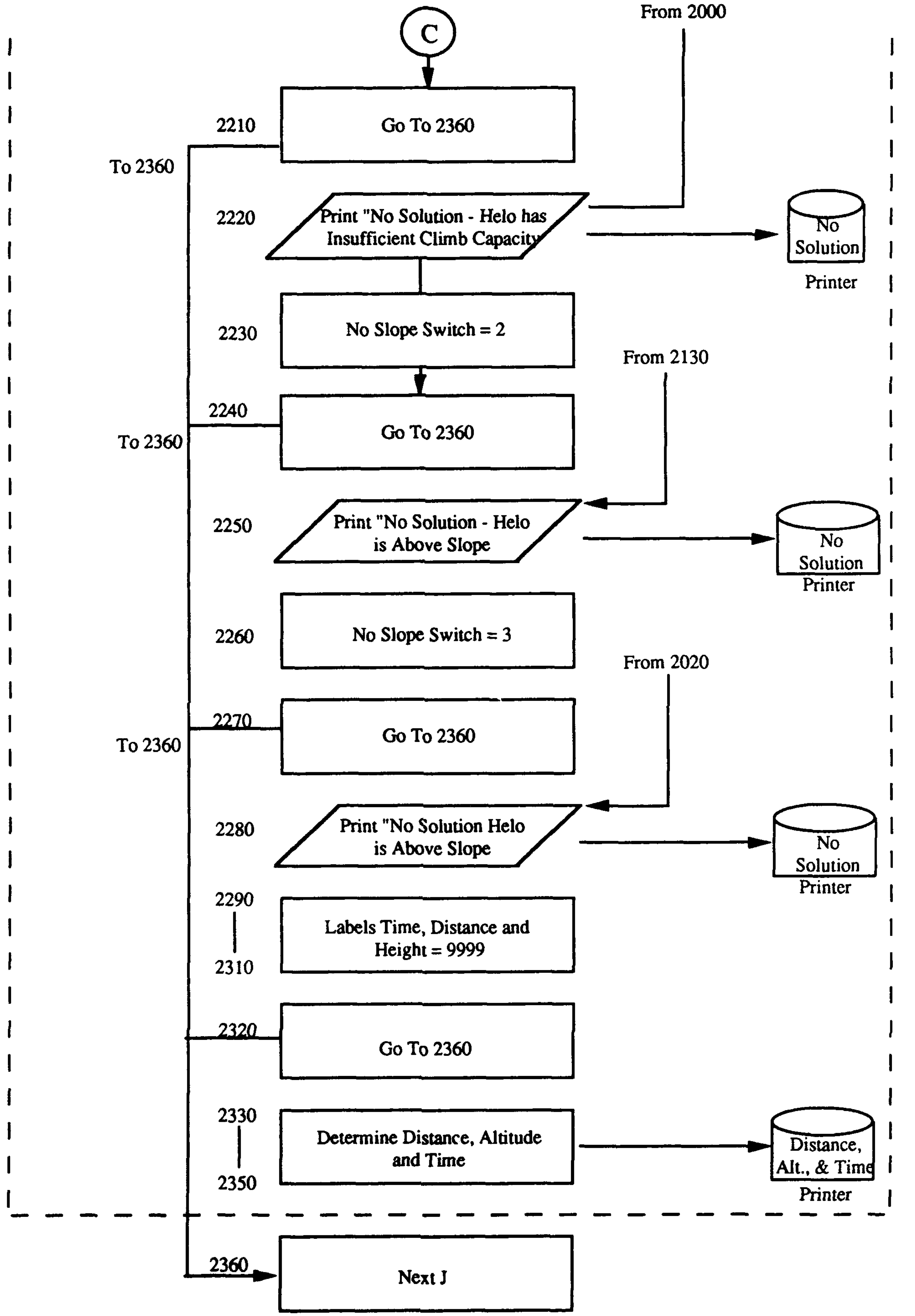

FIGURE 3 FLOW CHART FOR THE HV + 5 KNOTS PROCEDURE (CONTINUED)

TABLE 5
FLOW CHART NARRATIVE

90-120	INPUT CAS TO IAS CORRECTION. Reads the calibrated to indicated airspeed corrections which were taken from the flight manual.
130-350	DEFINE HELO PARAMETERS AND ATMOSPHERIC CONDITIONS. Helicopter parameters defined are rotor diameter and takeoff weights. Atmospheric conditions defined are pressure altitudes temperatures, air density ratios, and density altitudes.
360-430	OUTPUT HEADINGS TO #2 FILE. Titles each of the data columns in the number two file.
440	FOR EACH TEST CASE. Establishes a file for each of the eighteen cases by using a for-next loop with step 2870.
450-470	COMPUTE CASE NUMBER. Computes each of the case numbers.
490-620	COMPUTE IAS TO CAS CORRECTION. Indicated airspeed corrections must be interpolated. Calculations require the use of two loops, the outside loop computes the indicated airspeed and the inside loop interpolates between VCALTOIND values.
630-730	DETERMINE CASE CONDITIONS. Determines which density altitude, pressure altitude, temperature and aircraft weight to use for each of the cases.
740-860	PRINT CASE HEADINGS. Prints file name and case conditions.
880-1070	INPUT HELICOPTER PERFORMANCE DATA. Inputs the helicopter climb and acceleration data contained in the UNIV$ file. checks that the data is the correct length.
1080-1130	COMPUTE VHVP5. Converts the climbout phase indicated airspeed (VHVP5) to true airspeed.
1140-1190	COMPUTE ROTATESPEEDTRUE. Converts the indicated airspeed at the beginning of the acceleration phase (rotatespeed) to true airspeed.
1200-1270	COMPUTE DISTANCE, ALTITUDE AND TIME OF LEVEL FLIGHT. Determines the values of the first phase of flight. Half of the minimum final approach and takeoff area (FATO) length defined as HALFPADSIZE is subtracted from the level a flight distance (DLEVEL) This correction enables the helicopter to accelerate over half the FATO before distances from the FATO are computed.
1280-1350	PRINT DISTANCE, TIME AND ALTITUDE OF LEVEL FLIGHT. Prints the data computed in steps 1200-1270.
1360-1430	DEFINE PARAMETERS AND COMPUTE SLOPE OF ACCELERATING FLIGHT AND ROTATE RATE OF CLIMB.

TABLE 5

FLOW CHART NARRATIVE (continued)

1440-1790	COMPUTE RATES OF CLIMB, DISTANCE AND TIME OF ACCELERATING FLIGHT. Establishes a loop which computes and totals the distance covered and time required to climb every one foot of altitude from SKIDHEIGHT to HVMAXHEIGHT. Refer to figure 2C.
1800-1870	PRINT TIME. DISTANCE AND ALTITUDE OF ACCELERATING FLIGHT. Prints the data computed in steps 1530-1880.
1880-1910	DEFINE REFERENCE SLOPES. Defines reference slopes of 8:1, 7:1, 6:1, and 5:1.
1920-2360	COMPUTE AND PRINT INTERCEPT OF DEPARTURE PATH WITH REFERENCE SLOPES. Reference flow chart C.
2370-2410	OUTPUT PREVIOUSLY COMPUTED VALUES TO THE #2 FILE. Outputs the data computed in steps 2010-2440.
2420-2540	OUTPUT IF HELO IS ABOVE SLOPE (A/S) OR IF SLOPE IS UNATTAINABLE (S/U) TO THE #2 FILE.

TABLE 6
DEFINITIONS OF HEDPRO TERMS

ACCELDIST - Acceleration distance. The horizontal distance the helicopter travels as a function of its airspeed.

ACCELTIME - Acceleration time. The time required for the helicopter to accelerate to the corresponding airspeed.

ALTCASE - Altitude case. The pressure altitude to be used in the cases.

ANGLE OF CLIMB - The helicopter's angle of climb.

A/S - Above slope.

CDIST - The length of the acceleration climb segment.

CLIMB RAD - The helicopter's departure path slope expressed in radius .

D. ACCEL - Distance of acceleration flight. The horizontal distance of the acceleration flight segment.

D. ATL - Density Altitude.

D. LEV - Distance of level flight. (refer to figure 1).

D. SLOPEADJ - The distance measured from the end of the helicopter pad to the point where the helicopter climb path intercepts the reference slope.

F. ELEV - Field elevation.

FRACTION - The fractional ratio between the climb and acceleration data where a specific reference point exists.

H. LEV - Height of level flight (refer to figure 1).

HVMAXHEIGHT - Height at which the climbout at the HV+5 airspeed begins (refer to figure 1).

MAXGROSS - Helicopter maximum gross weight.

ROCFPM - Rate of climb (feet per minute). The helicopter's maximum rate of climb as a function of airspeed.

ROTATEROC - Rate of climb at the end of level flight (refer to figure 1).

ROTATESPEED - Airspeed at the end of level flight (refer to figure 1).

SIGMA - Air density ratio.

SLOPERAD - The reference slopes expressed in radians.

S/U - Slope unattainable.

TSLOPE - Time at which the helicopter intercepts the reference slope.

TABLE 6
DEFINITIONS OF HEDPRO TERMS (continued)

TEMPCASE - Temperature case, 0 an 20 degrees represent ISA and ISA + 20^{o} Celsius temperature.

T.DEV - Temperature deviation. Refer to TEMPCASE.

T.LEV - Time of level flight.

T.ACCEL - Time of acceleration flight. The time required for the helicopter to travel the acceleration flight segment.

THETA - The reference slopes expressed in degrees.

T.VTOS - Time to VTOSS (refer to figure 1).

UNIVS - Helicopter climb and acceleration data provided by the University of Maryland.

VLEV - Helicopter airspeed at the end of level flight (refer to figure 1).

VCALTOIND - Velocity, calibrated to indicated. The airspeed correction which is the difference between calibrated airspeed and indicated airspeed.

VINDTOCAL - Velocity, indicated to calibrated. The airspeed correction which is the difference between indicated airspeed and calibrated airspeed.

VELKNOTS - Helicopter true airspeed.

VHP5INDICATED - Velocity; height velocity plus 5 indicated (refer to VHVP5CAL definition).

VHVP5CAL - Velocity, height velocity plus 5 calibrated. Helicopter calibrated airspeed which is 5 knots greater than the minimum airspeed at the knee of the H-V diagram.

VHVP5TRUE - Velocity, height velocity plus 5 true (refer to VHVP5CAL definition).

WEIGHT - Weight of the helicopter.

WTCASE - Percentage of helicopter maximum gross weight.

7.0 GENERATING DEPARTURE PROFILES

The final step involves creating departure profiles from the HEDPRO DATA. A graphics program, GEMGRAPH which has line graph design capability, was well suited for this purpose. GEMGRAPH, is a product of Digital Research, Inc. and provides a straightforward method for converting data into line graphs.

The HEDPRO data did however need to first be converted into a comma separated variable (CSV) format which could later be read by GEMGRAPH. The program S76A FMT.BAS was developed for this purpose. This program is provided in appendix C.

GEMGRAPH's departure profile is presented in figure 4. For the H-V+5 knots procedure, the first flight segment represents a level acceleration at 5 feet to a speed of 29 KIAS. The second segment represents a climbing acceleration to 23 feet and 35 knots. The last segment presents a constant airspeed climbout of 35 KIAS.

For the Category A manufacturer's recommended procedure, the first segment represents a level acceleration at 5 feet to 35 KIAS. The second segment represents a climb at constant airspeed to 40 feet (critical decision point). The third segment presents a level acceleration at 40 feet to best rate of climb speed, Vy which is 52 KIAS. The final segment is a constant airspeed climbout at best rate of climb speed.

The manufacturer's recommended procedure has three segments. The first is a level acceleration at 5 feet to 45 KIAS. The second segment is a climbing acceleration to 52 KIAS and the last segment is a constant airspeed climbout at 52 KIAS.

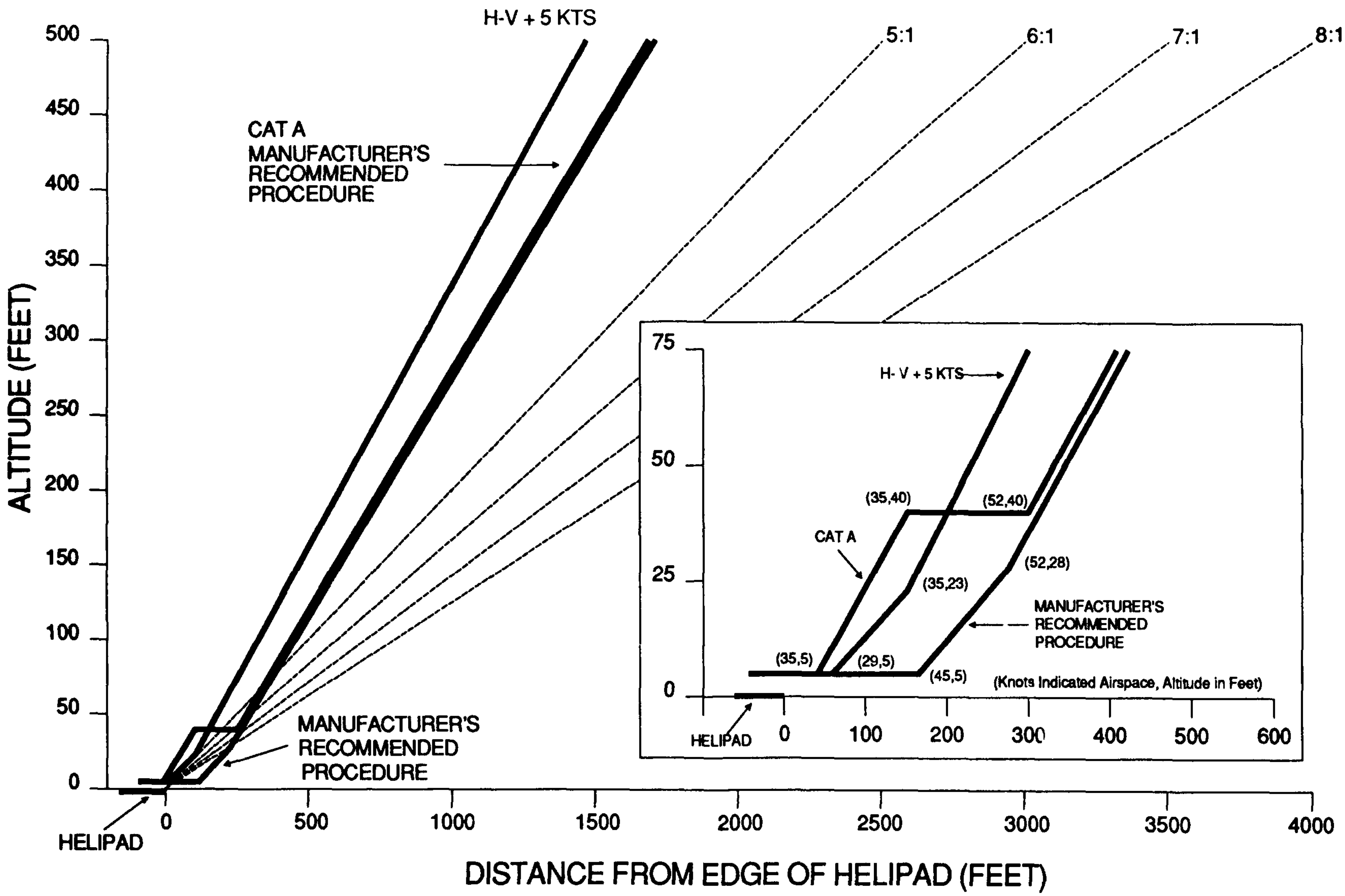

FIGURE 4 S 76A DEPARTURE PROFILES MAX. G.W. SEA LEVEL, STANDARD DAY

8.0 CONCLUSION

Detailed modeling of the S76A at maximum gross weight using the HV+5 Knots procedure at sea level and standard conditions has been incorporated into the step by step analysis of this report. Minor modifications are required to the HEDPRO program to adapt the HV+5 Knot procedures to other departure procedures. All the other steps necessary to create a profile remain essentially the same.

Accurate modeling of the helicopter departure profiles required exacting attention to detail. Small oversights in any of the steps often produced significant errors in the profiles. Because of the possibility of errors, the aircraft physical data, departure procedures and departure profiles were checked for accuracy by the helicopter manufacturer. Inaccuracies were corrected, the departure profiles were recreated and the information was then rechecked by the manufacturer.

The software programs used for the modeling produced only small errors. The helicopter acceleration and climb performance data produced by HESCOMP has been proven to be accurate to within ten percent of actual flight performances. HEDPRO then converts the climb and acceleration data into departure profile data. HEDPRO is accurate except that it can slightly underestimate the departure capability of the helicopter during the acceleration phase. This error is very small, however, and its effect on the profile is nearly insignificant. The remaining software that was used does not impart any known errors.

The modeling techniques and software created for this project can also be applied to other helicopters and rotorcraft to accurately create helicopter departure profiles.

GLOSSARY OF TERMS

CAT A — Category A requirements apply to helicopters over 20,000 pounds with 10 or more passenger seats as stated in 14 CFR, Part 29 regulations. Takeoff performances requirements are that, should an engine fail after takeoff, the aircraft can either return to and stop safely on the takeoff area, or continue the takeoff and climbout to attain:

1. at least VTOSS and an altitude of 35 feet and then climb 100 feet above the takeoff surface,
2. 150 feet/min rate of climb at 100 feet above the takeoff surface with maximum continuous power (30-minute power where certified).

CAT B — Category B requirements apply to helicopters weighing 20,000 pounds or less and having 9 or less passenger seats. However, a Category B aircraft with 10 or more seats must meet the one engine inoperative requirements of Category A.

CDP — Critical Decision Point. For Category A takeoffs, the combination of speed and altitude which determines whether, in the event of an engine failure, the helicopter could continue the takeoff.

H-V — Height Velocity Envelope. Defines conditions of height and speed from which a safe landing cannot be made in the event of a power failure. For Category B rotorcraft with single engines and multiengine rotorcraft without approved engine isolation, the safe operating envelope must be demonstrated with complete power failure. For Category A rotorcraft and Category B multiengine rotorcraft where engine isolation procedures ensure continued operation of the remaining engine(s), the safe operating envelope can be demonstrated with the critical engine inoperative.

VTOSS — Takeoff Safety Speed. For Category A takeoffs, the speed at which 100 FPM rate of climb is assured for all combinations of weight, altitude, temperature and center of gravity, for which takeoffs are to be scheduled. VTOSS is determined with landing gear extended, the critical engine inoperative and the remaining engine(s) within approved operating limits.

Vy — Best Rate of Climb Speed. The speed at which the maximum rate of climb can be achieved.

APPENDIX A
EXAMPLE HEIGHT-VELOCITY DIAGRAMS

TYPE	HELICOPTER
MAXIMUM CONDITIONS HV DIAGRAM	HUGHES 500E
DENSITY ALTITUDE HV DIAGRAM	ENSTROM F28
OPERATIONAL CONDITIONS HV DIAGRAM	AEROSPATIALE AS355F

Hughes Helicopters, Inc.
Hughes 500E Helicopter (Model 369E)

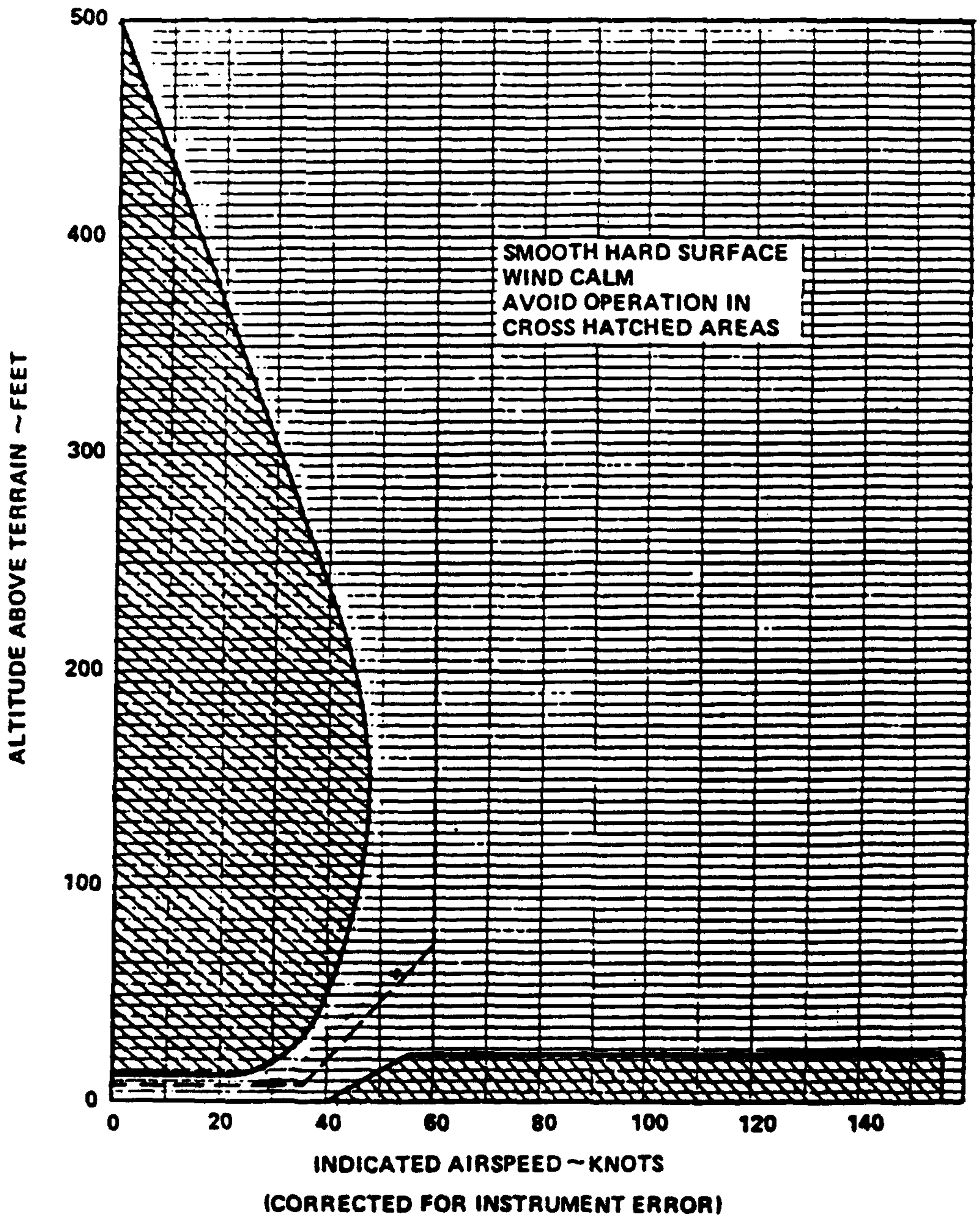

FIGURE A-1 HEIGHT VELOCITY DIAGRAM - HUGHES 500E

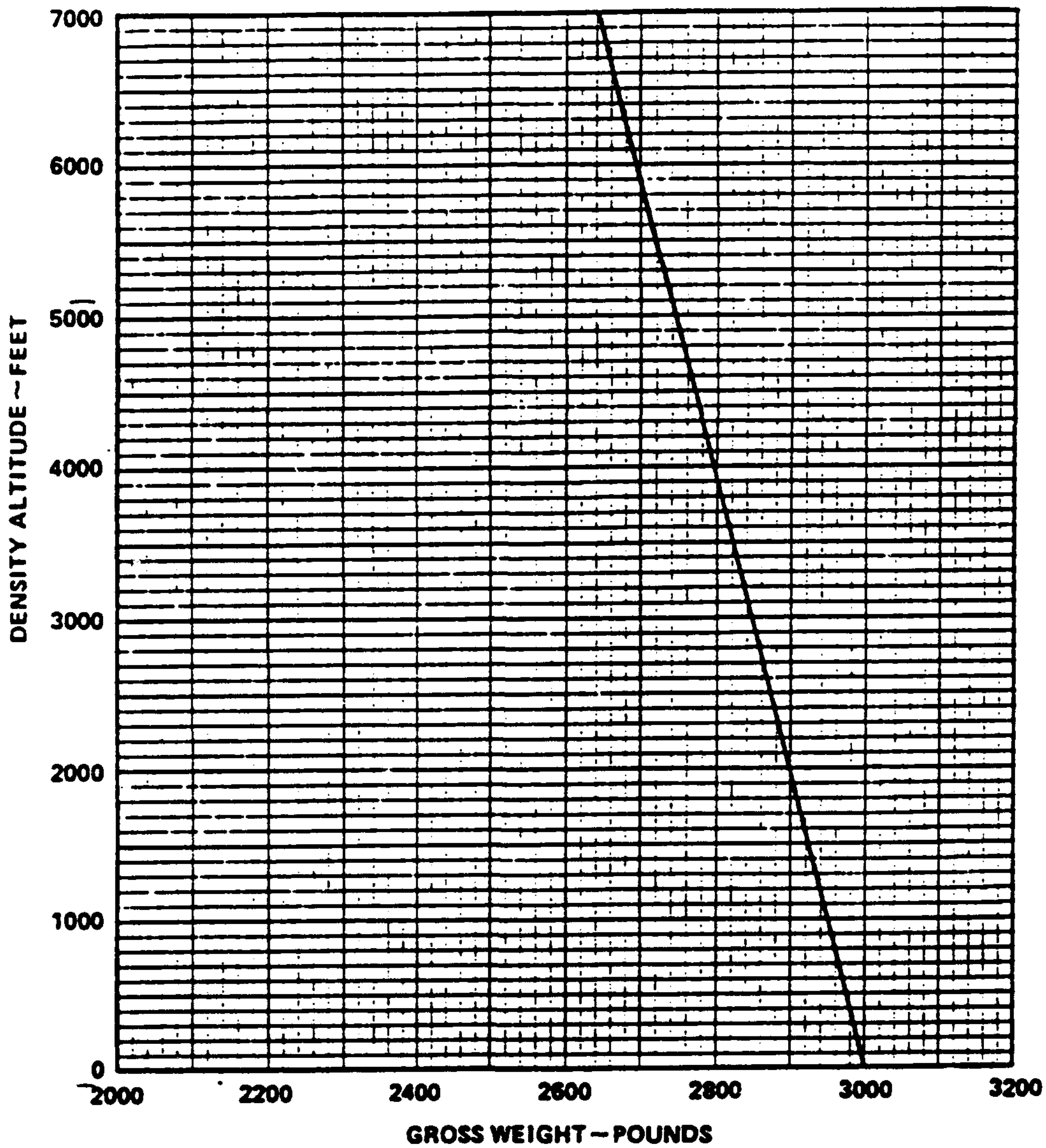

FIGURE A-2 GROSS WEIGHT LIMITS FOR HEIGHT VELOCITY DIAGRAM - HUGHES 500E

HEIGHT VELOCITY DIAGRAM

2350 LBS GROSS WEIGHT

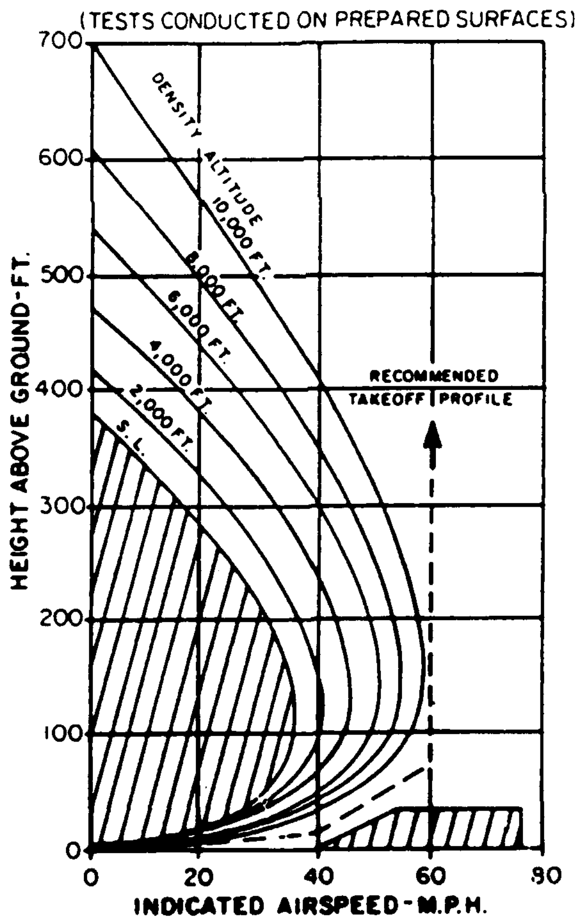

FIGURE A-3 HEIGHT VELOCITY DIAGRAM - EMSTROM F28F

EFFECT OF LOADING ON
CHOICE OF H-V ENVELOPE

The H-V curves presented in Figure 5.5 are valid for operations at 2350 lb gross weight for the specific density altitude conditions presented. For operation at other than 2350 lb gross weight, determine the proper H-V curve to be used for the intended gross weight and density altitude for the flight from the curves presented in Figure 5.6 below. For operations above 2500 lb gross weight, use the H-V curves presented in Figure 5.7 in place of Figures 5.6 and 5.5.

Example: (1) A gross weight of 2000 lbs and 3900 ft H_d would allow the use of the sea level envelope.

(2) A gross weight of 2200 lbs and 4500 ft H_d would require a 2800 ft curve. to be conservative, use the next higher curve, 4000 ft.

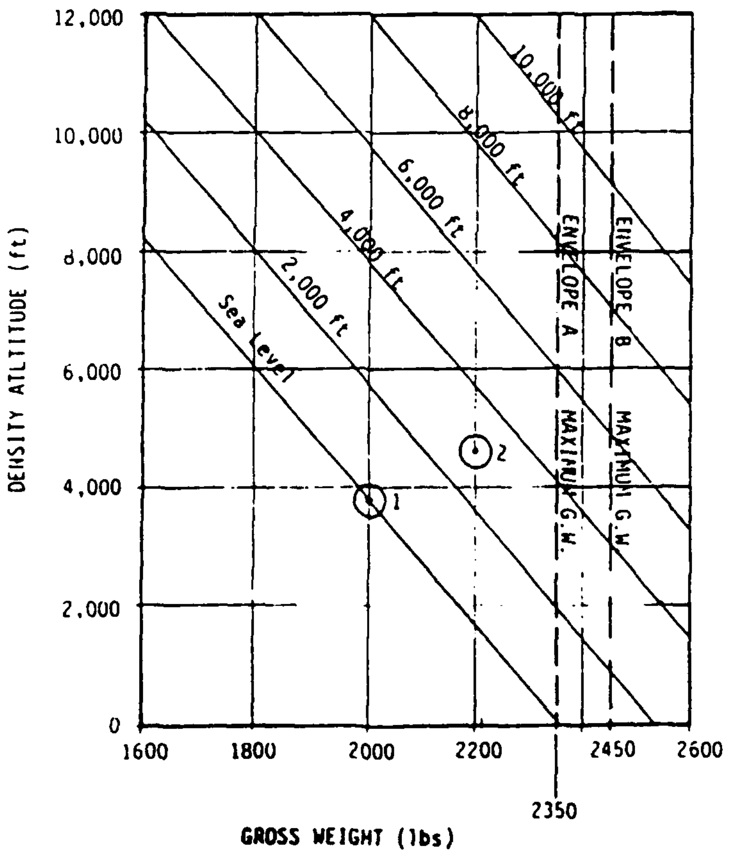

FIGURE A-4 EFFECT OF LOADING ON CHOICE OF H-V ENVELOPE - F28F

HEIGHT VELOCITY DIAGRAM

2600 LBS GROSS WEIGHT

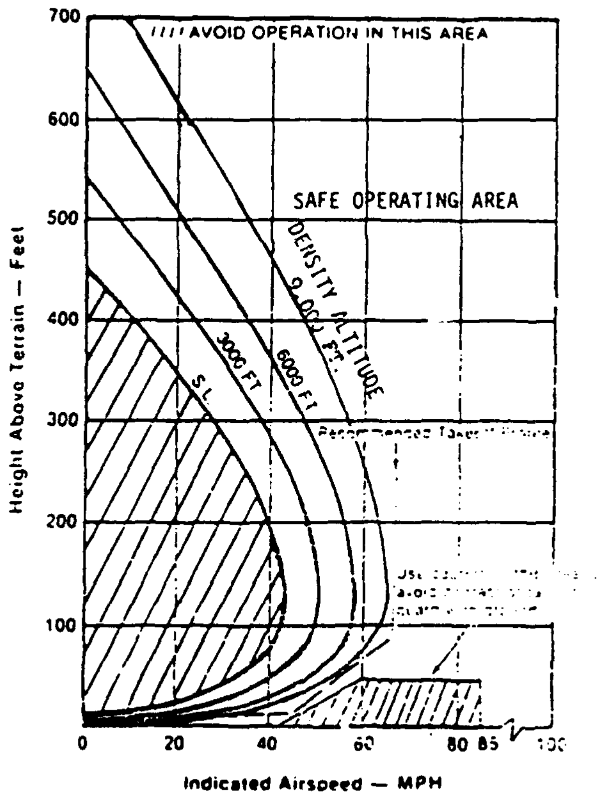

FIGURE A-5 HEIGHT VELOCITY DIAGRAM - F28F

HOW TO USE THE FIGURE RELATED TO HEIGHT - VELOCITY

For an all-up weight above 2150 kg (4720 lb), the aera to be avoided is defined by the three points A, B and C.

Determining point B

Point B is fixed and located at a 50 ft (15 m) height for a 30 kt (56 km/h - 35 MPH) velocity.

Determining points C and A

Points C and A are determined at a zero velocity and depend upon the actual weight and pressure - altitude.

- From the pressure - altitude (1), read across to the actual weight (2)
- Read vertically down to curves (3) and (4)
- From (3) and (4) read across to the height of points C and A

NOTE : When points C and A coincide, there is no unsafe area any longer
Example : 2000 ft and 2300 kg

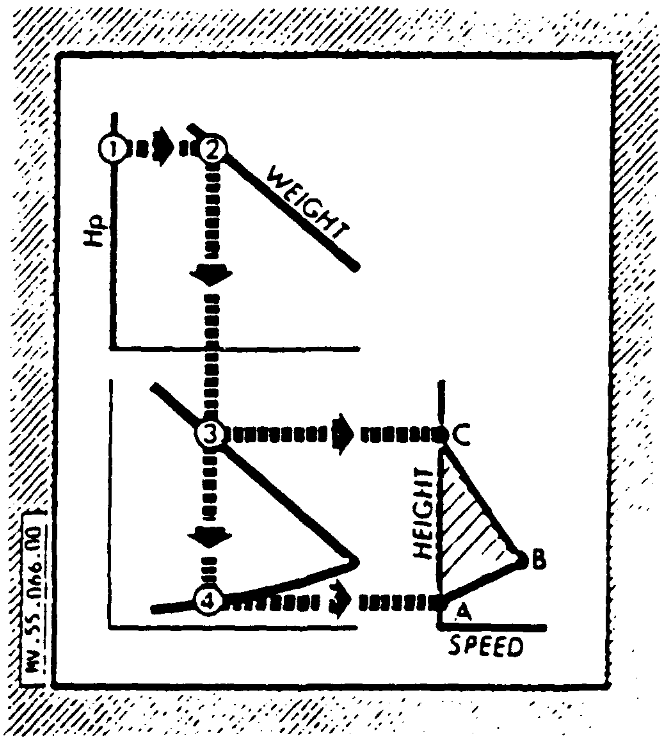

FIGURE A-6 DETERMINING THE HEIGHT VELOCITY - AS 355F

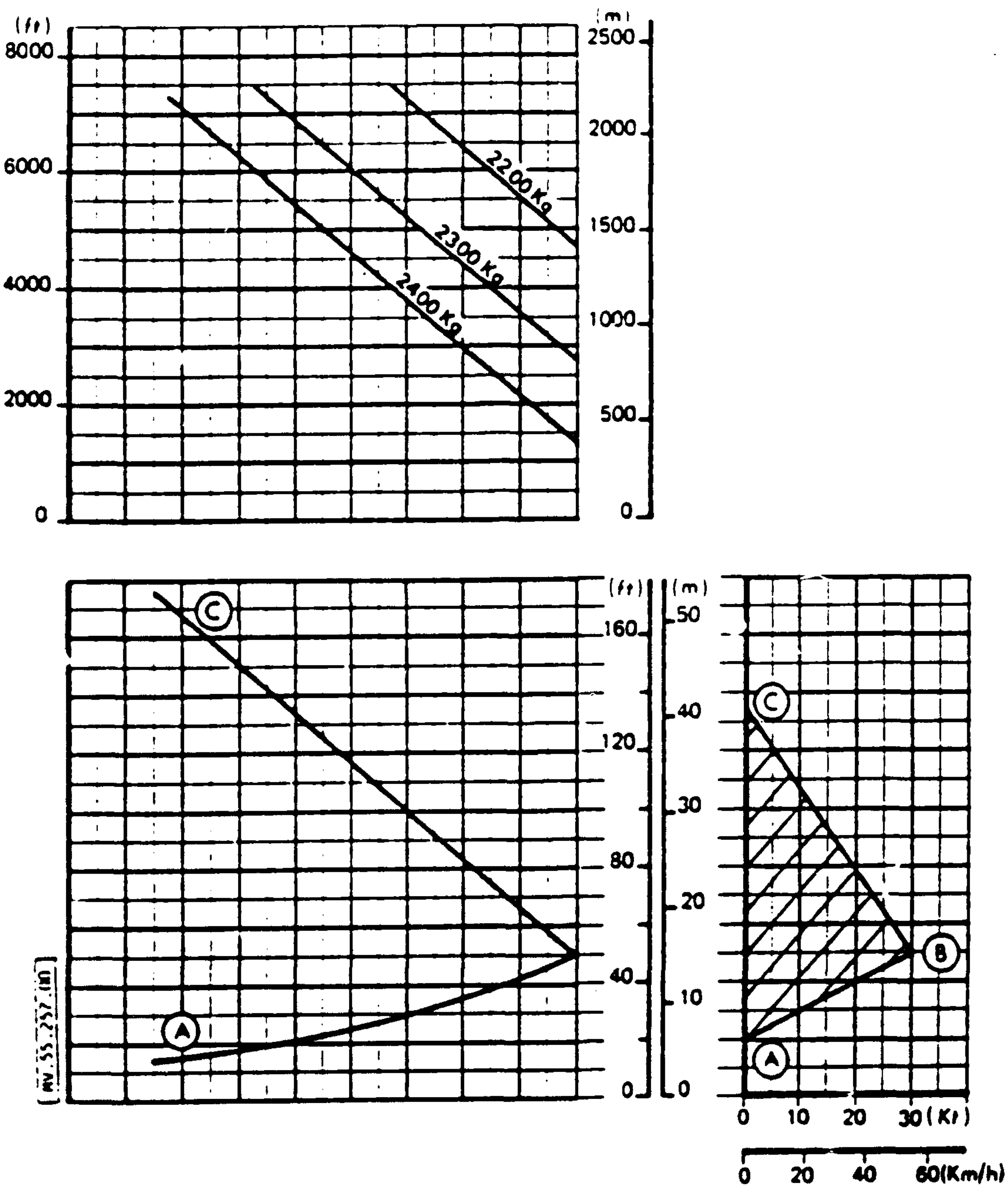

FIGURE A-6 DETERMINING THE HEIGHT VELOCITY DIAGRAM - AS 355F (Continued)

APPENDIX B
HEDPRO PROGRAM

```
 REM DATE: 11-20-89    TIME: 21:00
20 REM PROGRAM "S76A-HV+5" IS USED TO COMPUTE CLIMB PROFILES FROM DATA
30 REM PROVIDED BY THE UNIVERSITY OF MARYLAND.  THE -HV+5 VERSION
40 REM REPRESENTS THE HEIGHT-VELOCITY DIAGRAM + 5 KNOTS PROCEDURE.
50 REM
60 DIM UNIV$(60), VELKNOTS(40), ROCFPM(40), ACCELDIST(40), ACCELTIME(40)
70 DIM ANGLEOFCLIMB(40),VCALTOIND(40),VINDTOCAL(40)
80 PI= 3.1415927#
90 FOR K=0 TO 20
100 READ VCALTOIND(K)
110 NEXT K
120 DATA 0,0,0,0,-1,-3,-4,-4,-4,-3,2,2,2,1.5,1.5,1,1,1,1,1,1
130 ROTORDIAMETER=44
140 HALFPADSIZE=ROTORDIAMETER
150 MAXGROSS=10500
160 WTCASE(1)=1!
170 WTCASE(2)=.85
180 WTCASE(3)=.7
190 ALTCASE(1)=0
200 ALTCASE(2)=2000
210 ALTCASE(3)=4000
220 TEMPCASE(1)=0
230 TEMPCASE(2)=20
240 SIGMA(1)=1!
250 SIGMA(2)=.9351
260 SIGMA(3)=.9427
270 SIGMA(4)=.8808
280 SIGMA(5)=.8881
290 SIGMA(6)=.8289
300 DENSALT(1)=0
310 DENSALT(2)=2275
320 DENSALT(3)=2000
330 DENSALT(4)=4275
340 DENSALT(5)=4000
350 DENSALT(6)=6274
360 OPEN "O",#2,"C:\S76AO\S76A-OPT.PRN"
370 PRINT #2,"  WEIGHT F.ELEV.  T.DEV.  D.ALT.";
380 PRINT #2,"  D.LEV.  H.LEV.  T LEV.  V.LEV.";
390 PRINT #2," D.VTOS. H.VTOS. T.VTOS.   VTOS.";
400 PRINT #2,"   D.8:1   H.8:1   T.8:1";
410 PRINT #2,"   D.7:1   H.7:1   T.7:1";
420 PRINT #2,"   D.6:1   H.6:1   T.6:1";
430 PRINT #2,"   D.5:1   H.5:1   T.5:1"
440 FOR FILE=1 TO 18
450 FILE1%=INT(FILE/10)
460 FILE2%=INT(FILE-10*FILE1%)
470 FILENAME$="S76A"+MID$(STR$(FILE1%),2,1)+MID$(STR$(FILE2%),2,1)
480 OPEN "I",#1,"C:\S76AO\"+FILENAME$+".PRN"
490 FOR I1=0 TO 20
500 VIND1=5*I1
```

```
510 FOR I2=0 TO 22
520 VCAL2=5*I2
530 VIND2=VCAL2+VCALTOIND(I2)
540 IF VIND2>VIND1 THEN 550 ELSE 570
550 I2SAVE=I2
560 GOTO 580
570 NEXT I2
580 VINDO=5*(I2SAVE-1)+VCALTOIND(I2SAVE-1)
590 VCALO=5*(I2SAVE-1)
600 VCAL1=VCALO+(VIND1-VINDO)/(VIND2-VINDO)*5
610 VINDTOCAL(I1)=VCAL1-VIND1
620 NEXT I1
630 DENSALTNUM=FILE MOD 6
640 IF DENSALTNUM=0 THEN DENSALTNUM=6
650 WTNUM=INT((FILE+5)/6)
660 ALTNUM=INT((DENSALTNUM+1)/2)
670 TEMPNUM=DENSALTNUM MOD 2
680 IF TEMPNUM=0 THEN TEMPNUM=2
690 WT=MAXGROSS*WTCASE(WTNUM)
700 IF FILE=2 THEN WT=10400
710 IF FILE=4 THEN WT=10000
720 IF FILE=5 THEN WT=10395
730 IF FILE=6 THEN WT=9500
740 LPRINT "S76A - HEIGHT-VELOCITY +5 KNOTS PROCEDURE"
750 LPRINT DATE$,TIME$
760 LPRINT FILENAME$
770 LPRINT
780 LPRINT "WEIGHT = ";
790 LPRINT USING "######,.";WT;
800 LPRINT "      FIELD ELEVATION = ";
810 LPRINT USING "######,.";ALTCASE(ALTNUM);
820 LPRINT "      TEMP. DEV. = ";
830 LPRINT USING "####";TEMPCASE(TEMPNUM)
840 LPRINT "DENSITY ALTITUDE = ";
850 LPRINT USING "######,.";DENSALT(DENSALTNUM)
860 LPRINT
870 PRINT FILENAME$
880 NREC=-1
890 IF EOF(1)=-1 GOTO 1070
900 INPUT#1,UNIV$
910 VECTORLENGTH=LEN(UNIV$)
920 IF VECTORLENGTH<10 GOTO 890
930 IF VECTORLENGTH>35 THEN LPRINT "ERRONEOUS INPUT STRING"
940 IF VECTORLENGTH>35 THEN STOP
950 IF VECTORLENGTH=35 GOTO 1000
960 LOOP=35-VECTORLENGTH
970 FOR I=1 TO LOOP
980 UNIV$=" "+UNIV$
990 NEXT I
1000 NREC=NREC+1
1010 VELKNOTS(NREC)=5*NREC
1020 ROCFPM(NREC)=VAL(MID$(UNIV$,1,9))
1030 ANGLEOFCLIMB(NREC)=VAL(MID$(UNIV$,10,9))
1040 ACCELDIST(NREC)=VAL(MID$(UNIV$,19,9))
1050 ACCELTIME(NREC)=VAL(MID$(UNIV$,28,8))
```

```
1060 GOTO 890
1070 CLOSE#1
1080 VHVP5INDICATED=35
1090 K=INT(VHVP5INDICATED/5)
1100 FRACTION=VHVP5INDICATED/5-K
1110 VINDTOCAL=VINDTOCAL(K)+FRACTION*(VINDTOCAL(K+1)-VINDTOCAL(K))
1120 VHVP5CAL=VHVP5INDICATED+VINDTOCAL
1130 VHVP5TRUE=VHVP5CAL/SQR(SIGMA(DENSALTNUM))
1140 ROTATESPEEDINDICATED=29
1150 K=INT(ROTATESPEEDINDICATED/5)
1160 FRACTION=ROTATESPEEDINDICATED/5-K
1170 VINDTOCAL=VINDTOCAL(K)+FRACTION*(VINDTOCAL(K+1)-VINDTOCAL(K))
1180 ROTATESPEEDCAL=ROTATESPEEDINDICATED+VINDTOCAL
1190 ROTATESPEEDTRUE=ROTATESPEEDCAL/SQR(SIGMA(DENSALTNUM))
1200 SKIDHEIGHT=5
1210 HVMAXHEIGHT=23
1220 I=INT(ROTATESPEEDTRUE/5)
1230 FRACTION=ROTATESPEEDTRUE/5-I
1240 DLEVEL=ACCELDIST(I)+FRACTION*(ACCELDIST(I+1)-ACCELDIST(I))
1250 DLEVELADJ=DLEVEL-HALFPADSIZE
1260 TLEVEL=ACCELTIME(I)+FRACTION*(ACCELTIME(I+1)-ACCELTIME(I))
1270 HLEVEL=SKIDHEIGHT
1280 LPRINT "DIST-ADJ = ";
1290 LPRINT USING "#####..##": DLEVELADJ;
1300 LPRINT "      ALT = ";
1310 LPRINT USING "#####.#";HLEVEL;
1320 LPRINT "      TIME = ";
1330 LPRINT USING "####.##"; TLEVEL;
1340 LPRINT "      V-IND = ";
1350 LPRINT USING "####.##"; ROTATESPEEDINDICATED
1360 DELTAVI=VHVP5INDICATED-ROTATESPEEDINDICATED
1370 DELTAH=HVMAXHEIGHT-SKIDHEIGHT
1380 DELTAVIDELTAH=DELTAVI/DELTAH
1390 DELTAH=1
1400 ROTATEROC=ROCFPM(I)+FRACTION*(ROCFPM(I+1)-ROCFPM(I))
1410 ACCELCLIMBDISTANCE=0
1420 ACCELCLIMBTIME=0
1430 VINDICATED=ROTATESPEEDINDICATED
1440 FOR ALTITUDE=SKIDHEIGHT+DELTAH TO HVMAXHEIGHT STEP DELTAH
1450 DELTAVIND=DELTAVIDELTAH*DELTAH
1460 VINDICATEDLOWER=VINDICATED
1470 VINDICATEDUPPER=VINDICATED+DELTAVIND
1480 KLOWER=INT(VINDICATEDLOWER/5)
1490 KUPPER=INT(VINDICATEDUPPER/5)
1500 FRACTIONLOWER=VINDICATEDLOWER/5-KLOWER
1510 FRACTIONUPPER=VINDICATEDUPPER/5-KUPPER
1520 VINDTOCALLOWER=VINDTOCAL(KLOWER)+FRACTIONLOWER*(VINDTOCAL(KLOWER+1)
     -VINDTOCAL(KLOWER))
1530 VINDTOCALUPPER=VINDTOCAL(KUPPER)+FRACTIONUPPER*(VINDTOCAL(KUPPER+1)
     -VINDTOCAL(KUPPER))
1540 VCALLOWER=VINDICATEDLOWER+VINDTOCALLOWER
1550 VCALUPPER=VINDICATEDUPPER+VINDTOCALUPPER
1560 VTRUELOWER=VCALLOWER/SQR(SIGMA(DENSALTNUM))
1570 VTRUEUPPER=VCALUPPER/SQR(SIGMA(DENSALTNUM))
1580 ILOWER=INT(VTRUELOWER/5)
```

```
1590 IUPPER=INT(VTRUEUPPER/5)
1600 FRACTIONLOWER=VTRUELOWER/5-ILOWER
1610 FRACTIONUPPER=VTRUEUPPER/5-IUPPER
1620 ROCLOWER=ROCFPM(ILOWER)+FRACTIONLOWER*(ROCFPM(ILOWER+1)
     -ROCFPM(ILOWER))
1630 ROCUPPER=ROCFPM(IUPPER)+FRACTIONUPPER*(ROCFPM(IUPPER+1)
     -ROCFPM(IUPPER))
1640 ROCAVERAGE=(ROCLOWER+ROCUPPER)/2
1650 DISTANCEUPPER=ACCELDIST(IUPPER)+FRACTIONUPPER*(ACCELDIST(IUPPER+1)
     -ACCELDIST(IUPPER))
1660 DISTANCELOWER=ACCELDIST(ILOWER)+FRACTIONLOWER*(ACCELDIST(ILOWER+1)
     -ACCELDIST(ILOWER))
1670 TIMEUPPER=ACCELTIME(IUPPER)+FRACTIONUPPER*(ACCELTIME(IUPPER+1)
     -ACCELTIME(IUPPER))
1680 TIMELOWER=ACCELTIME(ILOWER)+FRACTIONLOWER*(ACCELTIME(ILOWER+1)
     -ACCELTIME(ILOWER))
1690 DELTACLIMBTIME=DELTAH/(ROCAVERAGE/60)
1700 CLIMBDISTANCE=((VTRUEUPPER+VTRUELOWER)/2)*(6076/3600)
     *DELTACLIMBTIME
1710 DELTADISTANCE=(DISTANCEUPPER-DISTANCELOWER)+CLIMBDISTANCE
1720 ACCELCLIMBDISTANCE=ACCELCLIMBDISTANCE+DELTADISTANCE
1730 DELTATIME=(TIMEUPPER-TIMELOWER)+DELTACLIMBTIME
1740 ACCELCLIMBTIME=ACCELCLIMBTIME+DELTATIME
1750 VINDICATED=VINDICATEDUPPER
1760 TOTALDISTANCE=DLEVEL+ACCELCLIMBDISTANCE
1770 TOTALDISTANCEADJ=TOTALDISTANCE-HALFPADSIZE
1780 TOTALTIME=TLEVEL+ACCELCLIMBTIME
1790 NEXT ALTITUDE
1800 LPRINT "DIST-ADJ = ";
1810 LPRINT USING "#####..##";TOTALDISTANCEADJ;
1820 LPRINT "      ALT = ";
1830 LPRINT USING "#####.#";ALTITUDE;
1840 LPRINT "      TIME = ";
1850 LPRINT USING "####.##";TOTALTIME;
1860 LPRINT "      V-IND = ";
1870 LPRINT USING "####.##";VINDICATEDUPPER
1880 THETA (1)=7.125
1890 THETA (2)=8.13
1900 THETA (3)=9.462
1910 THETA (4)=11.31
1920 FOR J=1 TO 4
1930 NOSLOPESWITCH(J)=1
1940 SLOPEDEGREES=THETA(J)
1950 LPRINT "SLOPE = ";
1960 LPRINT USING "####.###";SLOPEDEGREES;
1970 LPRINT " DEGREES"
1980 SLOPERAD=SLOPEDEGREES*PI/180
1990 CLIMBRAD=ATN((ROCUPPER/60)/(VHVP5TRUE*6076/3600))
2000 IF SLOPERAD>CLIMBRAD GOTO 2220
2010 DSLOPEADJ=(TOTALDISTANCEADJ*TAN(CLIMBRAD)-HVMAXHEIGHT)/
     (TAN(CLIMBRAD)-TAN(SLOPERAD))
2020 IF DSLOPEADJ>9999 GOTO 2280
2030 HSLOPE=DSLOPEADJ*TAN(SLOPERAD)
2040 TSLOPE=(HSLOPE-HVMAXHEIGHT)/(ROCUPPER/60)+TOTALTIME
2050 IF DSLOPEADJ>TOTALDISTANCEADJ GOTO 2150
```

```
2060 NUMERATOR=(HLEVEL*TOTALDISTANCEADJ)-(HVMAXHEIGHT*DLEVELADJ)
2070 DENOMINATOR=(TAN(SLOPERAD)*(TOTALDISTANCEADJ-DLEVELADJ))+
     (HLEVEL-HVMAXHEIGHT)
2080 DSLOPEADJ=NUMERATOR/DENOMINATOR
2090 HSLOPE=DSLOPEADJ*TAN(SLOPERAD)
2100 C=SQR(((TOTALDISTANCEADJ-DLEVELADJ)^2)+((HVMAXHEIGHT-HLEVEL)^2))
2110 CDIST=SQR(((DSLOPEADJ-DLEVELADJ)^2)+((HSLOPE-HLEVEL)^2))
2120 TSLOPE=(PERCENT*(TVTOSS-TLEVEL))+TLEVEL
2130 IF DSLOPEADJ>TOTALDISTANCEADJ GOTO 2250
2140 IF DSLOPEADJ<DLEVELADJ GOTO 2250
2150 LPRINT "DSLOPE = ";
2160 LPRINT USING "######..##";DSLOPEADJ;
2170 LPRINT "     HSLOPE = ";
2180 LPRINT USING "######..";HSLOPE;
2190 LPRINT "     TSLOPE = ";
2200 LPRINT USING "######.##";TSLOPE
2210 GOTO 2360
2220 LPRINT "NO SOLUTION - HELICOPTER HAS INSUFFICIENT CLIMB CAPABILITY"
2230 NOSLOPESWITH(J)=2
2240 GOTO 2360
2250 LPRINT "NO SOLUTION - HELICOPTER IS ABOVE SLOPE DURING DEPARTURE."
2260 NOSLOPESWITH(J)=3
2270 GOTO 2360
2280 LPRINT " NO SOLUTION - SLOPE UNACHIEVABLE WITHIN ALLOWABLE RANGE."
2290 DIST(J)=9999
2300 ALT(J)=9999
2310 TIME(J)=9999
2320 GOTO 2360
2330 DIST(J)=DSLOPEADJ
2340 ALT(J)=HSLOPE
2350 TIME(J)=TSLOPE
2360 NEXT J
2370 PRINT #2, USING "########";WT;ALTCASE(ALTNUM);TEMPCASE(TEMPNUM)
2380 PRINT #2, USING "########";DENSALT(DENSALTNUM);DLEVELADJ;HLEVEL;
2390 PRINT #2, USING "########";TLEVEL;ROTATESPEEDINDICATED;
2400 PRINT #2, USING "########";DVTOSSADJ;HVTOSS;
2410 PRINT #2, USING "########";TVTOSS;VTOSSINDICATED;
2420 FOR J=1 TO 4
2430 IF NOSLOPESWITCH(J)=2 GOTO 2480
2440 IF NOSLOPESWITCH(J)=3 GOTO 2500
2450 PRINT #2, USING "########";DIST(J);ALT(J);
2460 PRINT #2, USING "######.#";TIME(J);
2470 GOTO 2510
2480 PRINT #2,"     S/U     S/U     S/U";
2490 GOTO 2510
2500 PRINT #2,"     A/S     A/S     A/S";
2510 IF J=4 THEN PRINT #2, USING "##.#####";TAN(CLIMBRAD);
2520 IF J=4 THEN PRINT #2,
2530 NEXT J
2540 NEXT FILE
2550 CLOSE #2
2560 LPRINT CHR$(12)
2570 STOP
```

APPENDIX C
S76A FORMAT PROGRAM

```
10 REM PROGRAM "S76AFMT.BAS"
20 REM PROGRAM TO CONVERT BASIC OUTPUT FILES TO
30 REM XXX.CSV FILES FOR PLOTTING BY GEM
40 REM OCTOBER 21, 1988
50 BL$="    "
60 CM$=","
70 OPEN "I",#1,"C:\S76AO\S76A-OPT.PRN"
80 OPEN "I",#2,"C:\S76AB\S76A-B.PRN"
90 OPEN "I",#3,"C:\S76AA\S76A-A.PRN"
100 INPUT #1,A$
110 INPUT #2,B$
120 INPUT #3,C$
130 FOR I=1 TO 18
140 FILE=I
150 FILE1%=INT(FILE/10)
160 FILE2%=INT(FILE-10*FILE1%)
170 FILENAME$="C:\S76A\S76A"+MID$(STR$(FILE1%),2,1)+MID$(STR$(FILE2%),2,1)
180 OPEN"O",#4,FILENAME$+".CSV"
190 PRINT FILENAME$
200 INPUT #1,A$
210 IF LEN(A$) < 200 THEN A$= " "+A$
220 IF LEN(A$)=200 THEN 230 ELSE 210
230 INPUT #2,B$
240 IF LEN(B$) < 200 THEN B$=" "+B$
250 IF LEN(B$) = 200 THEN 260 ELSE 240
260 INPUT #3,C$
270 IF LEN(C$) < 224 THEN C$=" "+C$
280 IF LEN(C$) = 224 THEN 290 ELSE 270
290 IF I>1 THEN 310
300 MGW0=VAL(MID$(A$,1,8))
310 MGW=VAL(MID$(A$,1,8))
320 PERMGW=100*MGW/MGW0
330 FE=VAL(MID$(A$,9,8))
340 DELTEMP=VAL(MID$(A$,17,8))
350 DENSALT=VAL(MID$(A$,25,8))
360 X1=0
370 Y1=VAL(MID$(A$,41,8))
380 X2=VAL(MID$(A$,33,8))
390 Y2=Y1
400 X3=VAL(MID$(A$,65,8))
410 Y3=VAL(MID$(A$,73,8))
420 M=VAL(MID$(A$,193,8))
430 U4=X3+(500-Y3)/M
440 V4=500
450 R4=4000
460 S4=Y3+M*(4000-X3)
470 IF S4>500 THEN X4=U4
480 IF S4>500 THEN Y4=V4
490 IF S4<=500 THEN X4=R4
500 IF S4<=500 THEN Y4=S4
```

```
510 X5=0
520 Y5=VAL(MID$(B$,41,8))
530 X6=VAL(MID$(B$,33,8))
540 Y6=Y5
550 X7=VAL(MID$(B$,65,8))
560 Y7=VAL(MID$(B$,73,8))
570 M=VAL(MID$(B$,193,8))
580 U8=X7+(500-Y7)/M
590 V8=500
600 R8=4000
610 S8=Y7+M*(4000-X7)
620 IF S8>500 THEN X8=U8
630 IF S8>500 THEN Y8=V8
640 IF S8<=500 THEN X8=R8
650 IF S8<=500 THEN Y8=S8
660 XA1=0
670 YA1=VAL(MID$(C$,41,8))
680 XA2=VAL(MID$(C$,33,8))
690 YA2=YA1
700 XA3=VAL(MID$(C$,65,8))
710 YA3=VAL(MID$(C$,73,8))
720 XA4=VAL(MID$(C$,89,8))
730 YA4=VAL(MID$(C$,97,8))
740 M=VAL(MID$(C$,217,8))
750 UA5=XA4+(500-YA4)/M
760 VA5=500
770 RA5=4000
780 SA5=YA4+M*(4000-XA4)
790 IF SA5>500 THEN XA5=UA5
800 IF SA5>500 THEN YA5=VA5
810 IF SA5<=500 THEN XA5=RA5
820 IF SA5<=500 THEN YA5=SA5
830 X9=0
840 Y9=0
850 X10=4000
860 Y10=500
870 X11=3500
880 Y11=500
890 X12=3000
900 Y12=500
910 X13=2500
920 Y13=500
930 WRITE #4,X1,Y1,BL$,BL$,BL$,BL$,BL$,BL$
940 WRITE #4,X2,Y2,BL$,BL$,BL$,BL$,BL$,BL$
950 WRITE #4,X3,Y3,BL$,BL$,BL$,BL$,BL$,BL$
960 WRITE #4,X4,Y4,BL$,BL$,BL$,BL$,BL$,BL$
970 WRITE #4,X5,BL$,Y5,BL$,BL$,BL$,BL$,BL$
980 WRITE #4,X6,BL$,Y6,BL$,BL$,BL$,BL$,BL$
990 WRITE #4,X7,BL$,Y7,BL$,BL$,BL$,BL$,BL$
1000 WRITE #4,X8,BL$,Y8,BL$,BL$,BL$,BL$,BL$
1010 WRITE #4,XA1,BL$,BL$,YA1,BL$,BL$,BL$,BL$
1020 WRITE #4,XA2,BL$,BL$,YA2,BL$,BL$,BL$,BL$
1030 WRITE #4,XA3,BL$,BL$,YA3,BL$,BL$,BL$,BL$
1040 WRITE #4,XA4,BL$,BL$,YA4,BL$,BL$,BL$,BL$
1050 WRITE #4,XA5,BL$,BL$,YA5,BL$,BL$,BL$,BL$
```

```
1060 WRITE #4,X9,BL$,BL$,BL$,Y9,BL$,BL$,BL$
1070 WRITE #4,X10,BL$,BL$,BL$,Y10,BL$,BL$,BL$
1080 WRITE #4,X9,BL$,BL$,BL$,BL$,Y9,BL$,BL$
1090 WRITE #4,X11,BL$,BL$,BL$,BL$,Y11,BL$,BL$
1100 WRITE #4,X9,BL$,BL$,BL$,BL$,BL$,Y9,BL$
1110 WRITE #4,X12,BL$,BL$,BL$,BL$,BL$,Y12,BL$
1120 WRITE #4,X9,BL$,BL$,BL$,BL$,BL$,BL$,Y9
1130 WRITE #4,X13,BL$,BL$,BL$,BL$,BL$,BL$,Y13
1140 PRINT#4,"WEIGHT=";
1150 PRINT#4,USING "######";MGW;
1160 PRINT#4," LBS. (";
1170 PRINT#4,USING "###";PERMGW;
1180 PRINT#4," % MAX. GROSS WT.) "
1190 PRINT#4,"FIELD ELEVATION = ";
1200 PRINT#4,USING "#####";FE;
1210 PRINT#4," FT., "
1220 PRINT#4,"TEMP.DEV. = ";
1230 PRINT#4,USING "###";DELTEMP;
1240 PRINT#4," DEG. C., "
1250 PRINT#4,"DENSITY ALT. = ";
1260 PRINT#4,USING "######";DENSALT;
1270 PRINT#4," FT."
1280 CLOSE #4
1290 NEXT I
1300 STOP
1310 END
```

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